Physics 131
General Physics I
Grinnell College

Homework XIII

Session XIII.1

1. Explain what is wrong with the following statement:

> I flip a coin ten times, and record the results. Since each flip is as likely to produce a head as a tail, each particular string of heads and tails is just as likely as any other. Therefore, it is just as likely that I will flip heads ten times as it is that I will flip five heads and five tails.

2. Let's make a guess for how long we would have to wait to see all the air atoms in a balloon move to one side--it is of course possible at least in principle.

a. There are about 10^{22} atoms in a balloon. We found a single atom had a 50% chance of being on the left, so two atoms had a 50% times 50% chance of *both* being on the left, or 25%, so that three had a 12.5% chance of all three being on the left, and so on. If for any single atom there is a 50-50 chance of being on one side or the other, what is the probability that they will all be on the left side?

b. To change this probability into a waiting time, we need to divide it into the time it typically takes to change from one configuration into any other. A time that makes sense is the time it takes a single atom (moving at about the speed of sound, or 300 m/sec) to cross the 0.05 meters from one side of the balloon to the other. How long do we have to wait then to see this event with some reasonable probability?

[Extra challenge--not for credit. How small a balloon, assuming the same density of atoms, must we have to get a reasonable probability of having all the atoms on one side sometime during a time comparable to the age of the universe, or 10^{10} years?]

Session XIII.2

Let's see how close our two level system comes to satisfying the old rule of temperature as the average energy per atom. You will use the Entropy Calculator Excel sheet from class to do this in problems 3 and 4. In each case, use N = 1000 atoms in each of the two interacting systems.

3. Let's take a large amount of energy; let the total energy be 500.
   a) Find the distribution of energy between the two systems that maximizes the entropy.

   b) Find the average energy per particle in each system. How do they compare?

4. Let's take a small amount of energy; let the total energy be 50.

   a) Find the distribution of energy between the two systems that maximizes the entropy.

   b) Find the average energy per particle in each system. How do they compare?

   c) Which of the two cases--high energy or low energy--better satisfies the simple notion of equal temperatures (i.e. maximizing entropy) means equal energy per particle?

5. I claimed that the temperature was related to the derivative of the entropy with respect to energy. Check this out using the Entropy Calculator and see if pumping in more energy really does raise the temperature. That is, approximate dS/dE with $\Delta S/\Delta E$ for 1000 particles as you change the energy from 50 to 60, and then from 300 to 310. Calculate the temperature for each of these cases. Which is higher?

Session XIII.3

6. The tools of nuclear magnetic resonance (NMR) can also be applied to electrons in atoms. What is the population imbalance [Prob(up)/Prob(down)]-1 for an electron at room temperature in a 9 Tesla magnet? The magnetic moment of an electron is 9×10^{-24} J/T. Compare this to the population imbalance at a temperature of 4K.

7. The temperature on the surface of the sun is about 6000K. What is the relative probability of the n=2 excited state relative to the ground state n=1 of the hydrogen atom at this temperature? (Remember this number so you can compare to your calculation of this probability at room temperature, POD XIII.4 in class.)